Progressive Compression for Lossless Transmission of Triangle Meshes

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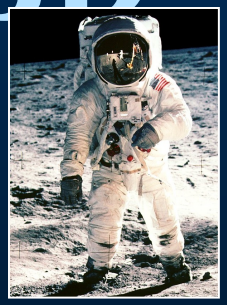
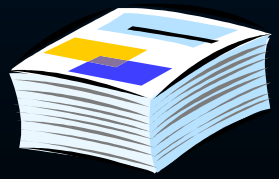
SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

Context: Transmission of 3D

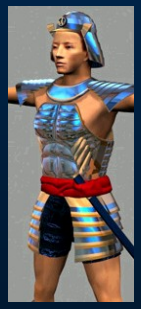




3D Data Compression

Different needs:

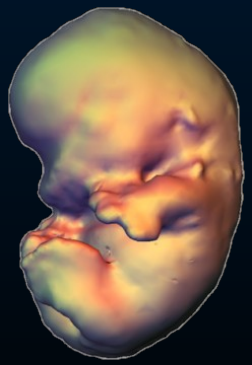
Lossy…

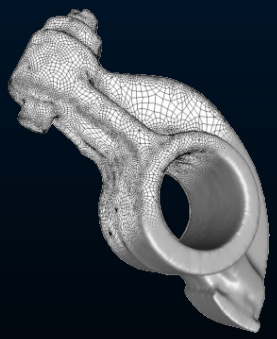


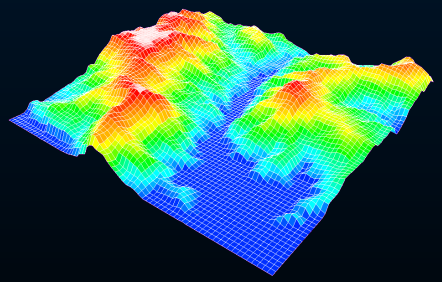
Games

Virtual malls

or Lossless?







Medical

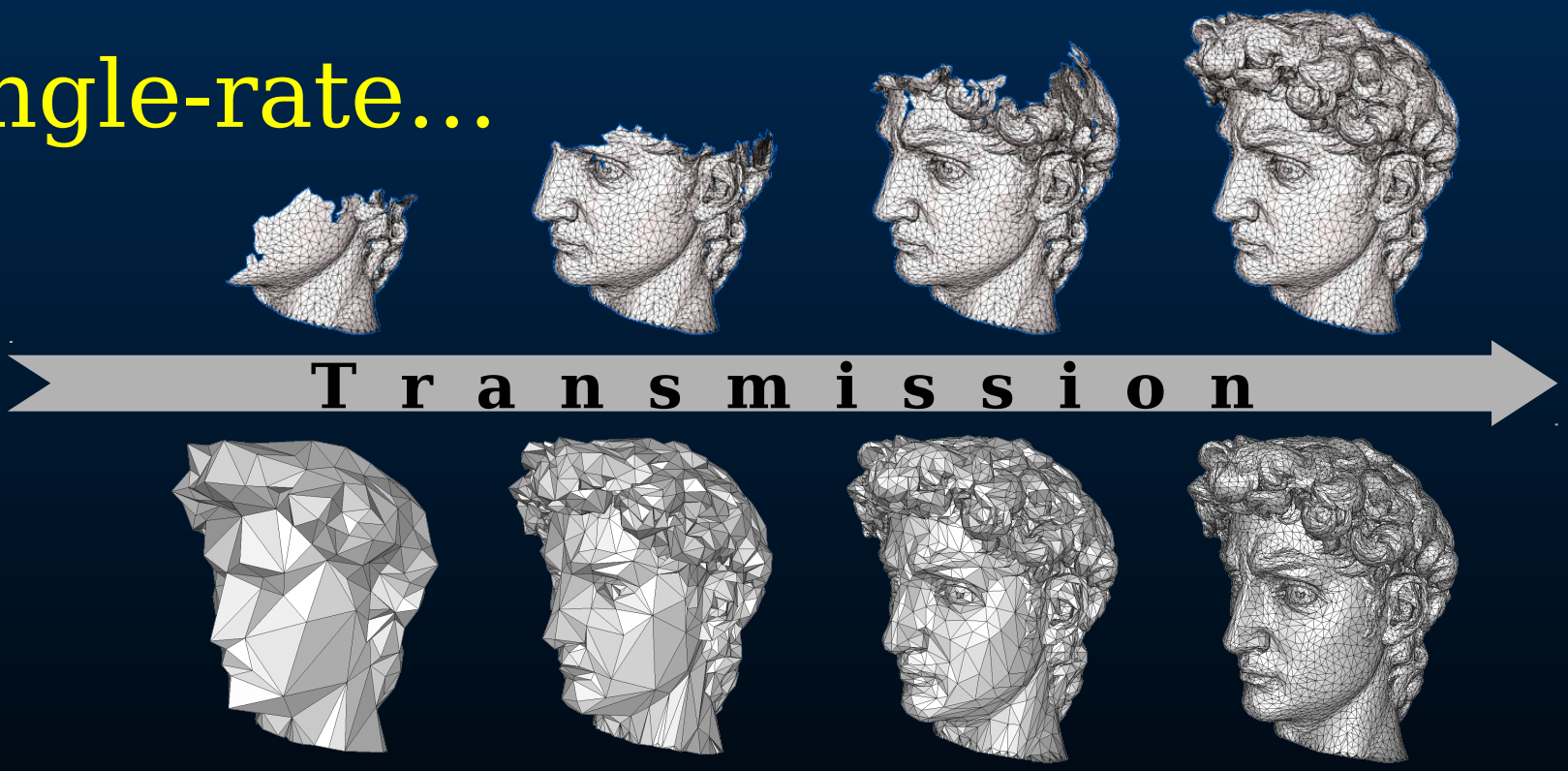
Engineering

Topography

3D Data Compression

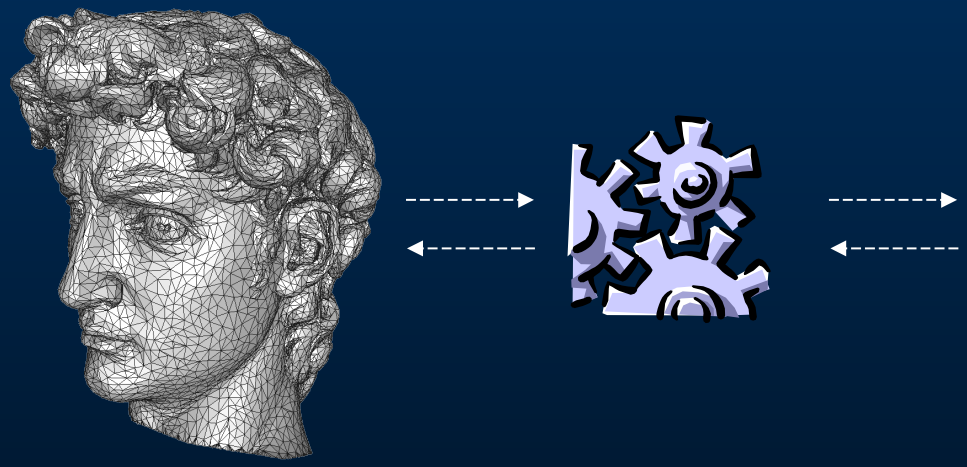
Different needs

Single-rate…



or Progressive?

Our Goal



...
0110110110001
0...

- Progressive compression
- Lossless transmission
- High compression rates

Layout

- Previous work
- Our approach
  - Valence-centered Decimation
  - Connectivity Encoding
  - Geometry Encoding
- Results
- Conclusions and Future Work

Previous work

PROGRESSIVE / LOSSLESS

96 Hoppe — **Progressive Meshes**

97 Denny - Sohler — **Edge Permutation Encoding**

98 Taubin et al. — **Progressive Forest Split Compressed Progressive Meshes**

99 Pajarola - Rossignac — **Progressive valence approach**

01 Alliez - Desbrun — **2/4 Coloring**

99 Cohen-Or et al.

PROGRESSIVE / LOSSY

00 Devillers - Gandoin — **Geometric Triangulation**

00 Karni - Gotsman — **Spectral Compression**

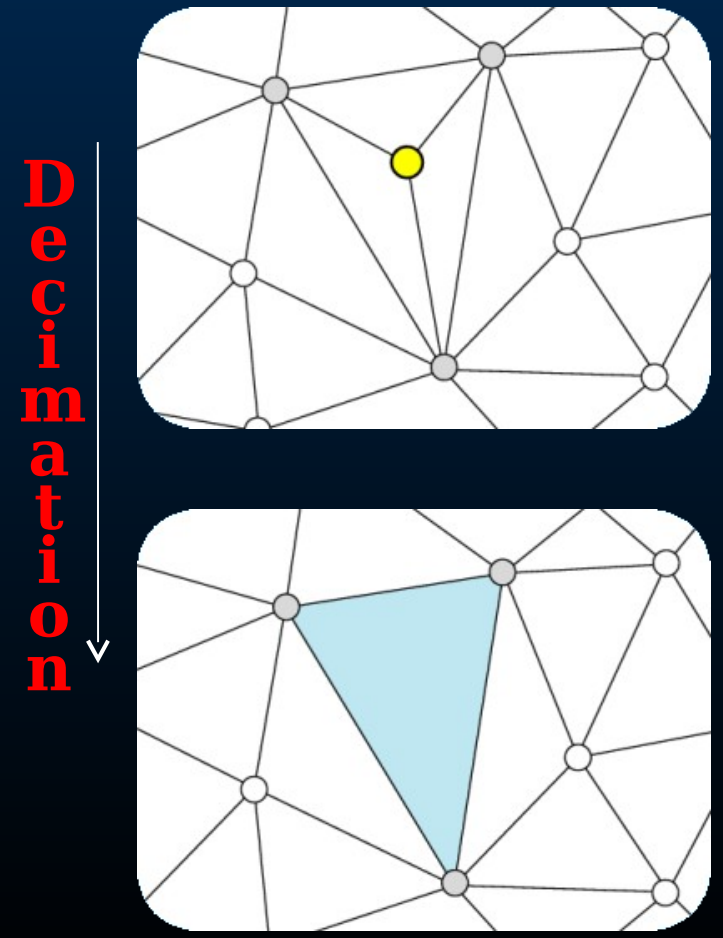
00 Khodakovsky et al. — **Remeshing**

Common ideas

Encoding decimation / refinements:

1. Localization
   where to refine?

2. Action
   how to refine?



Hoppe 96

1. Localization

each vertex to split

~ $\log_2(V)$ bits to localize

2. Action

Connectivity:

2 edges to split

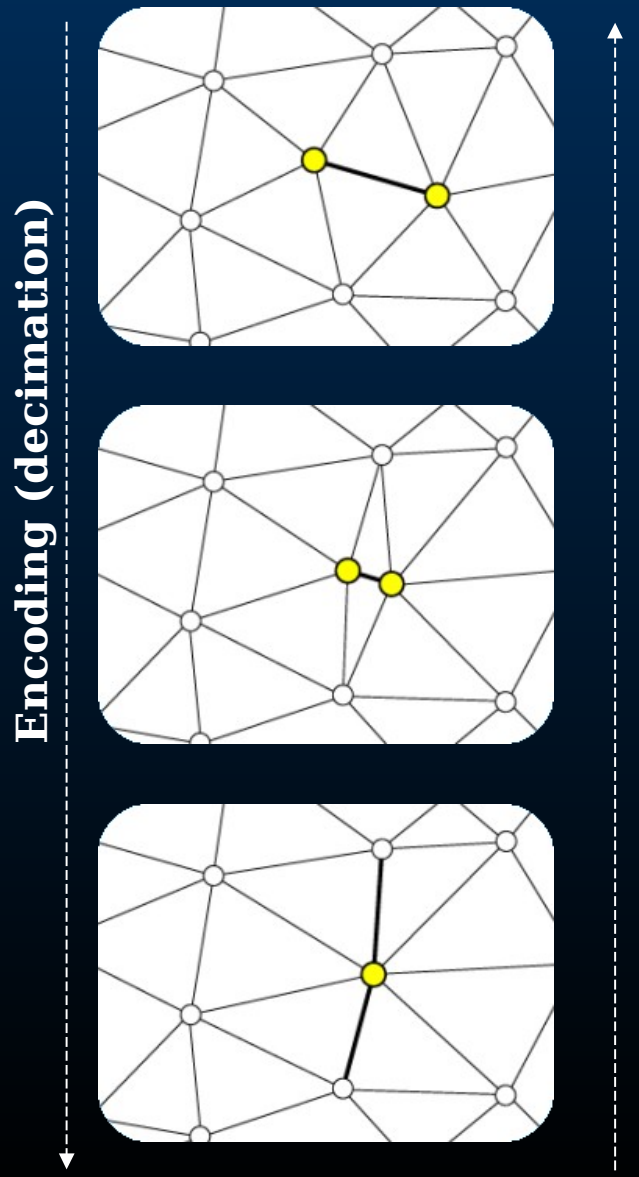
$\log_2(C_v^2)$

16 b/v

Geometry:

delta encoding

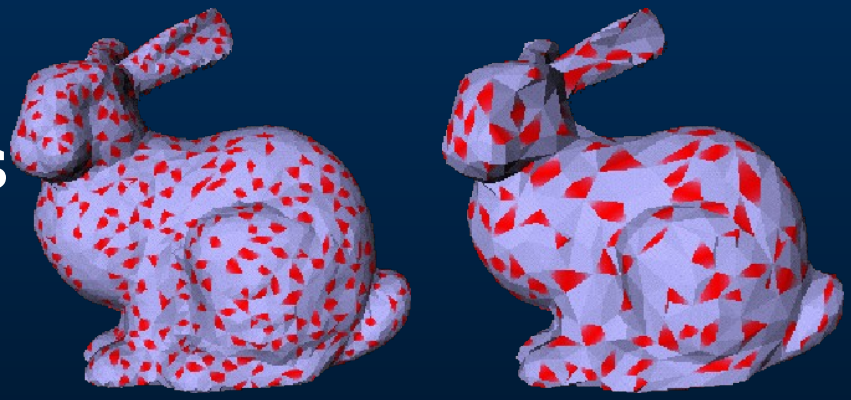
~20 b/v



Pajarola - Rossignac 99

1. Localization

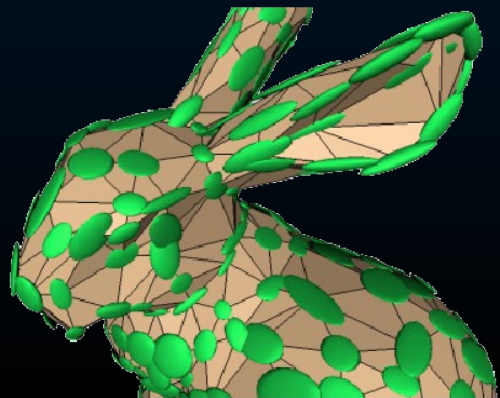
2 coloring over vertices
amortized cost : 3 b/v



2. Action

Connectivity:
2 edges to split
7.2 b/v

Geometry:
Butterfly prediction + metric
~17 b/v

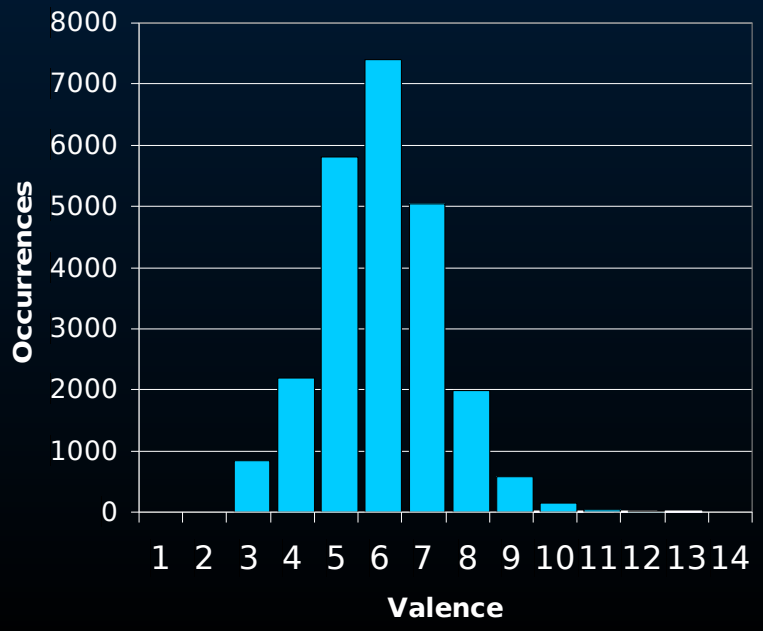


Valence-centered Approach?

We showed (Eurographics ’01) that valence

leads to optimal connectivity encoding

$$entropy = \sum_{i=1}^{N} p_i \log_2 \frac{1}{p_i}$$



Main Ideas

Connectivity:

Only one valence per vertex

- Sufficient for both localization and action
- Close to optimal compression **[AD 01]**

Geometry:

Normal/tangential separation

- Separate geometry/parameterization

[KSS 00]

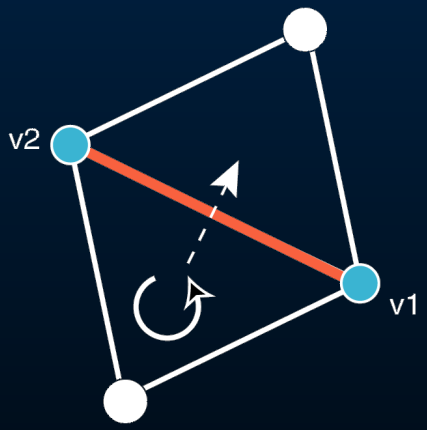
Our Method at a Glance

- **Decimation Strategy**
  - Passes of vertex removals
  - Automatic re-triangulation
- **Entropy Encoding**
  - Compression of the list of symbols

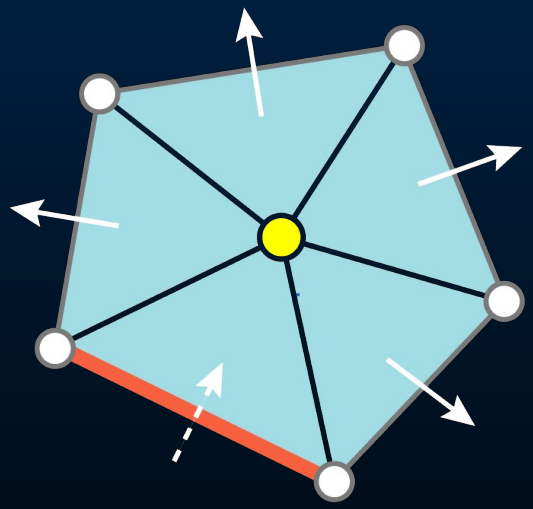
    (essentially valences)

Basic Primitives

Gate
(oriented edge)

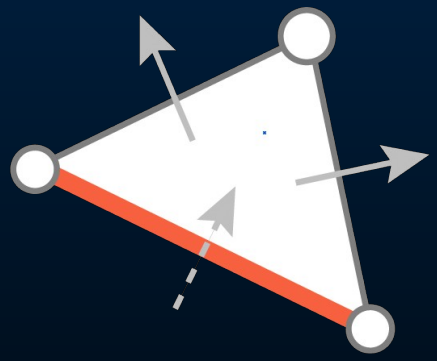


Ordinary patch



1 input gate
N-1 output gates
1 vertex removal

Null patch

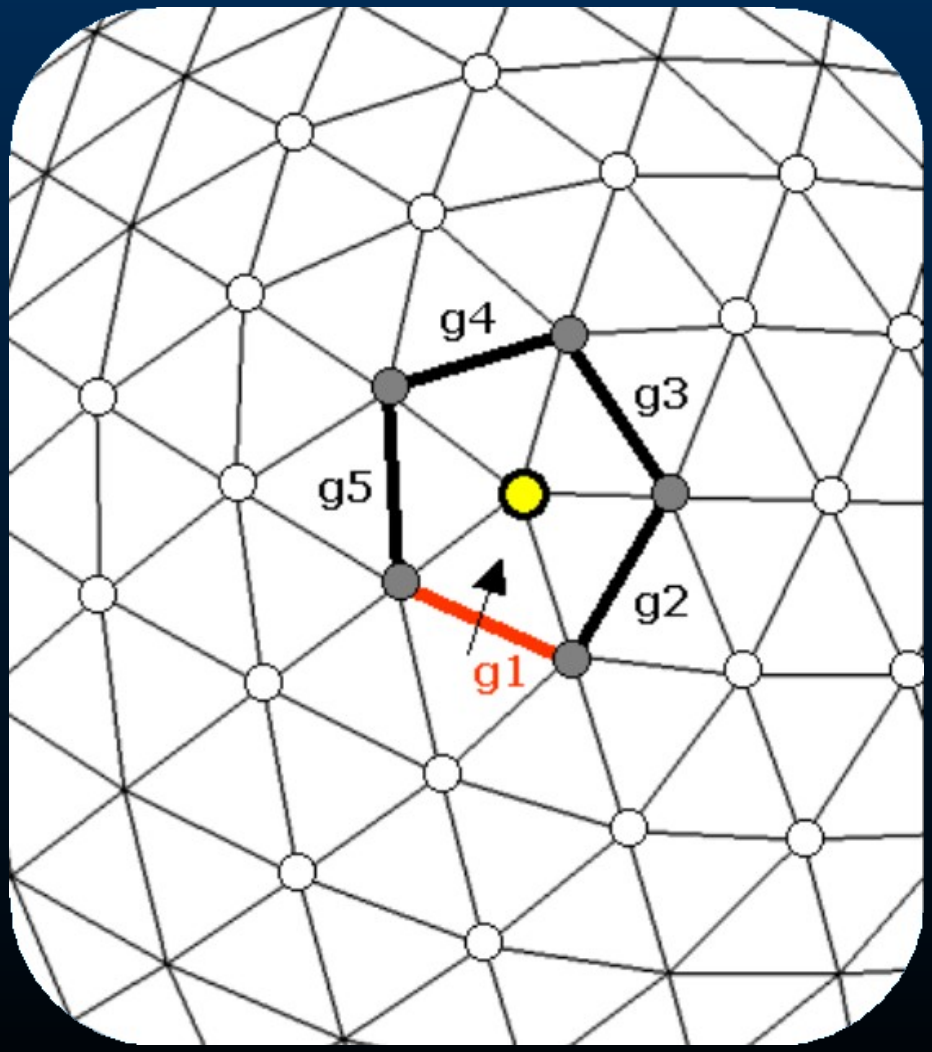


1 input gate
2 output gates
0 vertex remov

Decimation Strategy

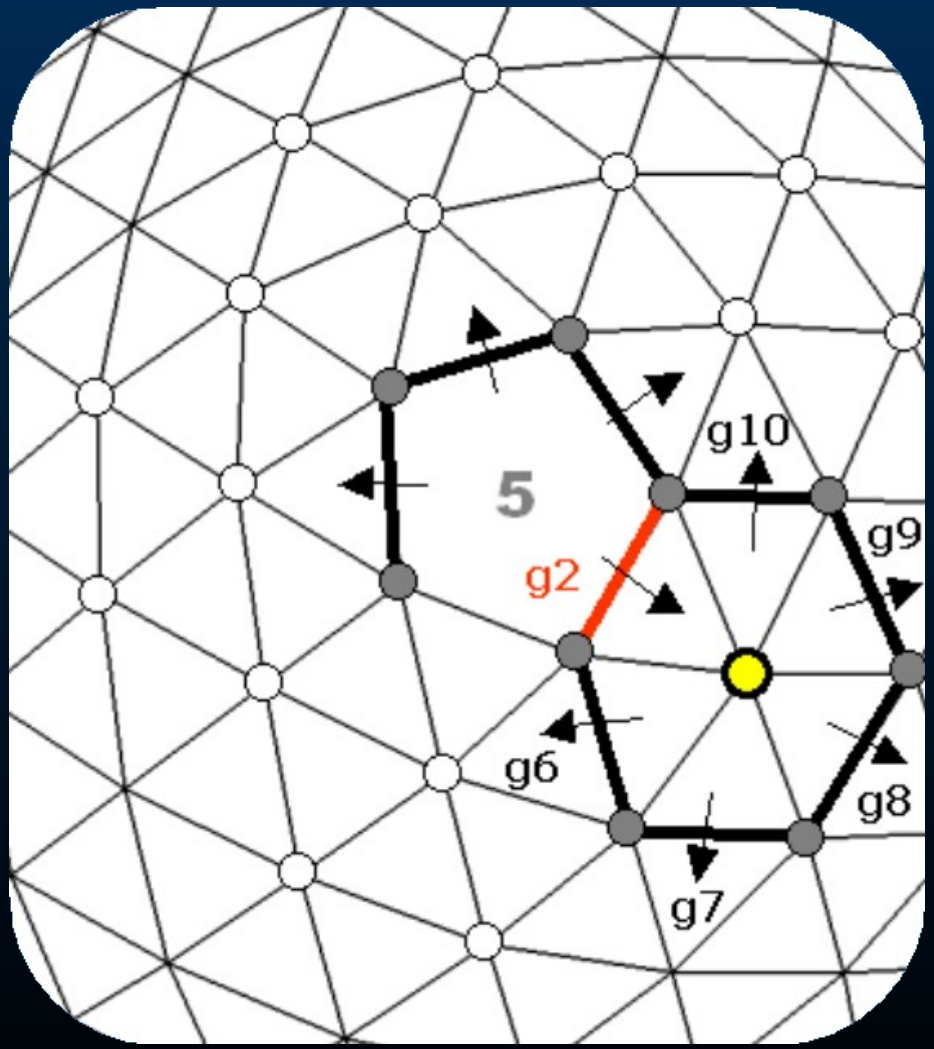
- Gate-based deterministic conquest
  - Vertex removal
  - Fifo of gates
  - Eliminate localization cost
- Targeting special vertices
  - Low valences to respect balance (**Denny - Sohler 97**)
  - Cosmetic decisions
- Automatic re-triangulation
  - Favor regular remeshing
  - Look-up table

Example of Conquest



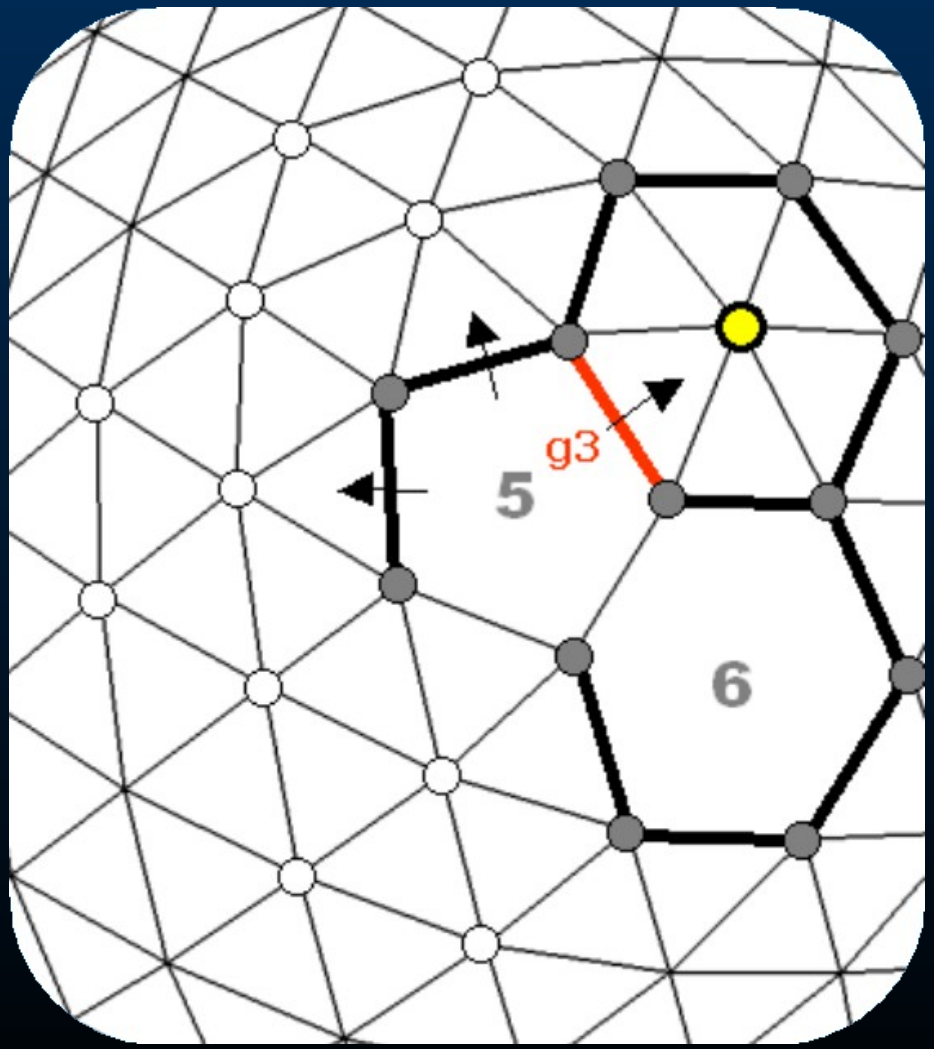
Codes	Fifo
5	g 1 g 2 g 3 g

Conquest - Step 2



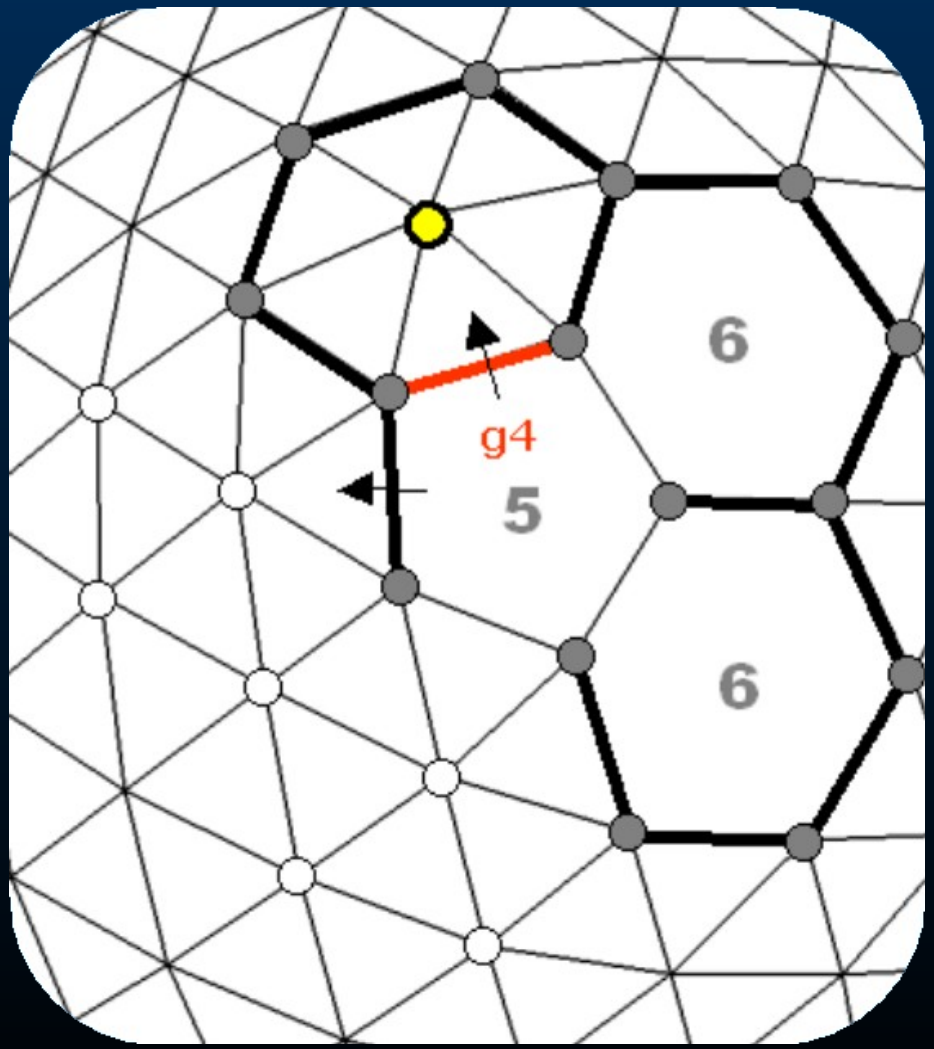
Codes	Fifo
6	g
5	2
	g
	3
	g
	4
	g

Conquest - Step 3



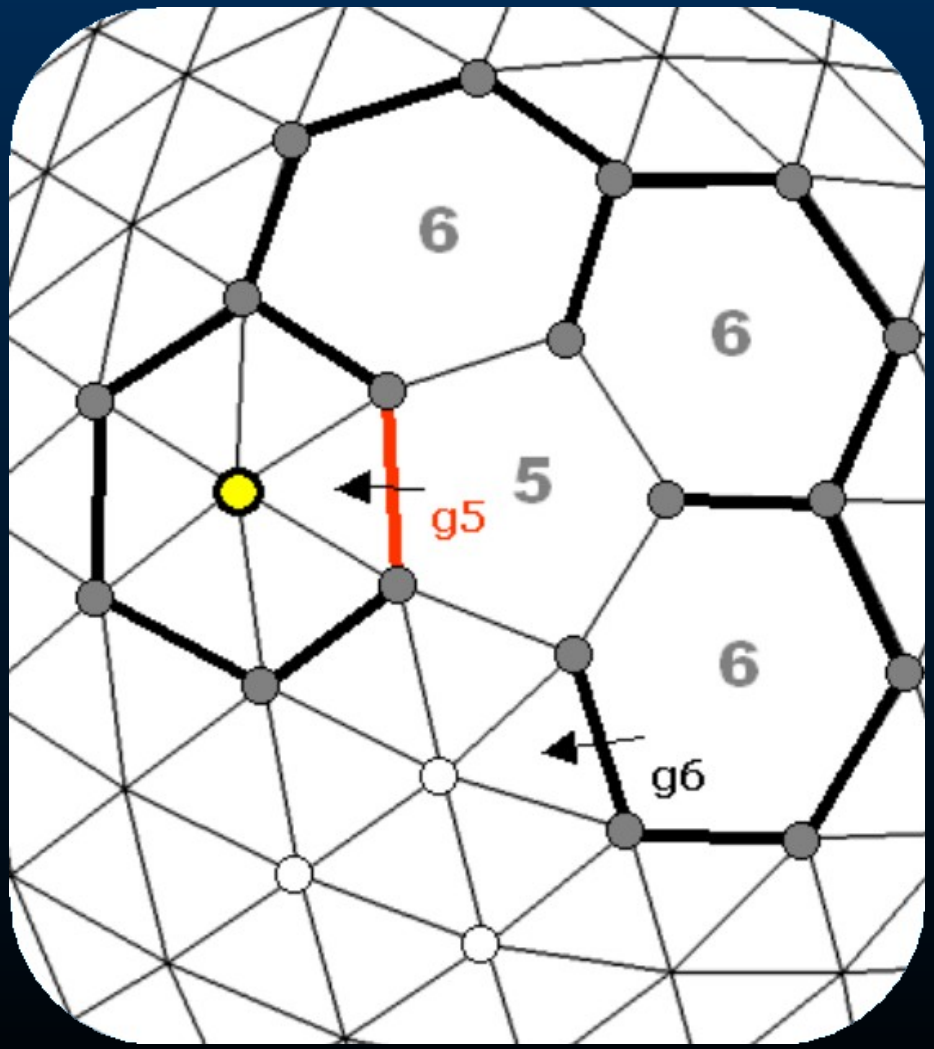
Codes	Fifo
6	g
6	3
5	g
	4
	g
	5
	g

Conquest - Step 4



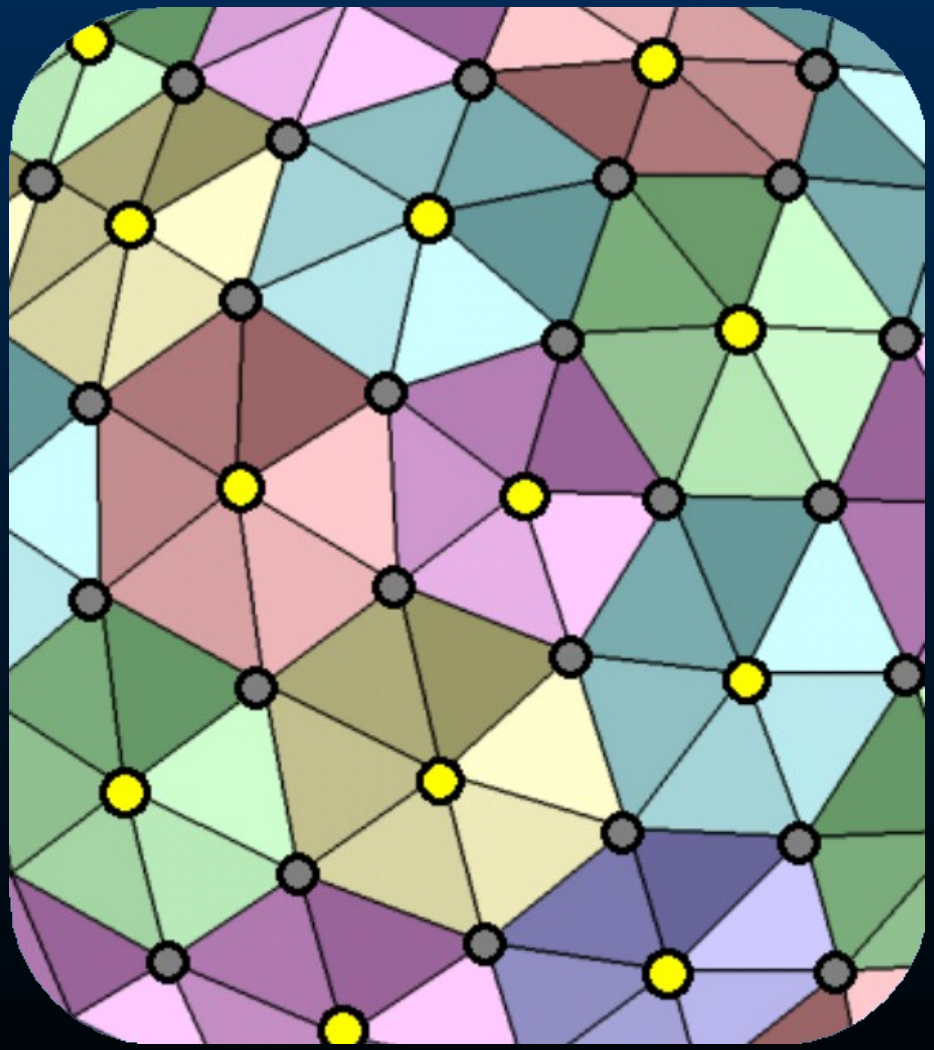
Codes	Fifo
6	g
6	4
6	g
5	5
	g
	6
	g

Conquest - Step 5



Codes	Fifo
6	g
6	5
6	g
6	6
5	g
	7
	g

Conquest - End



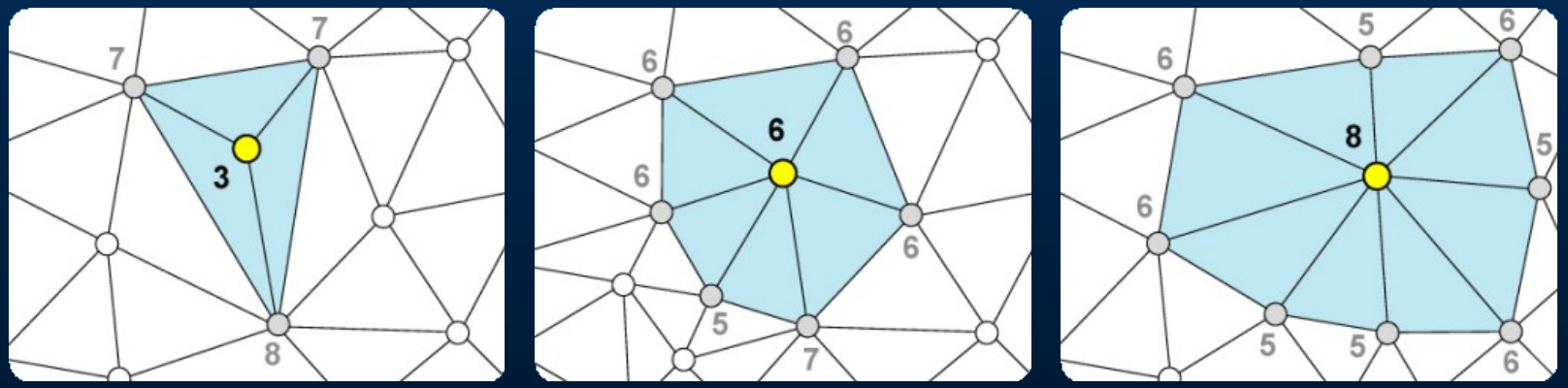
Codes	Fifo
6	
5	
6	
4	
5	
…	

Decimation Strategy

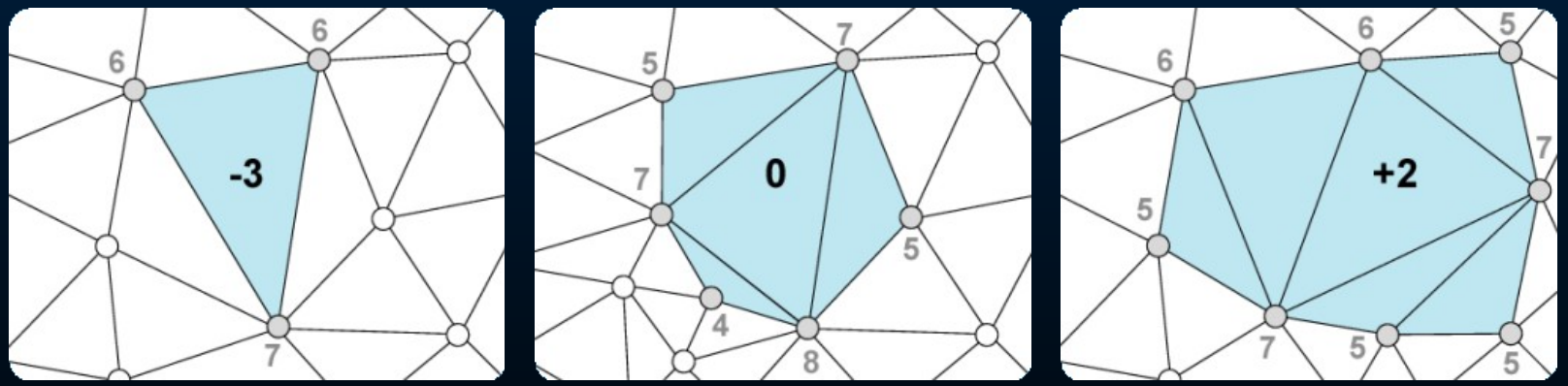
- Gate-based deterministic conquest
  - Vertex removal
  - Fifo of gates
  - Eliminate localization cost
- Targeting special vertices
  - Low valences to respect balance **[Denny - Sohler 97]**
  - Cosmetic decisions
- Automatic re-triangulation
  - Favor regular remeshing
  - Look-up table

Valence Dispersion

before



after



Before : V = Σ(valences, central vertex s excluded)

After : V' = Σ(valences)

V' = V + (valence(s)-6)

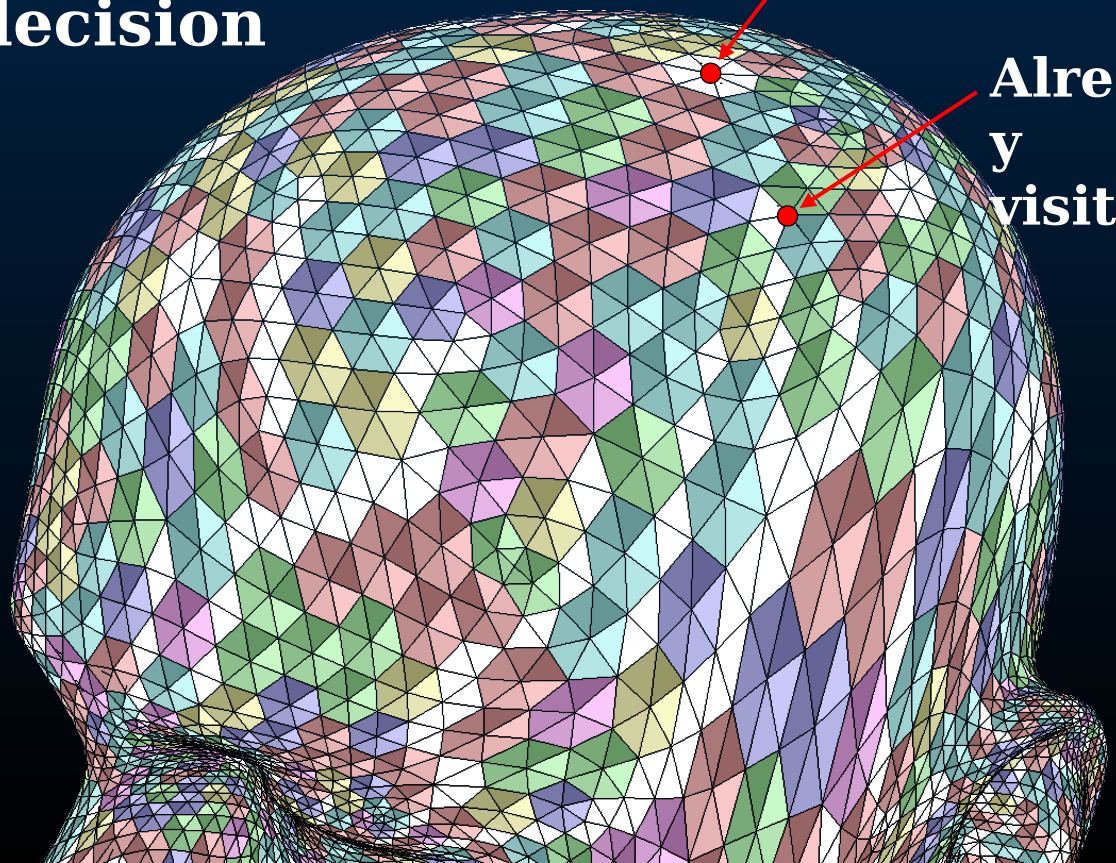
→ remove only valences [3-6]

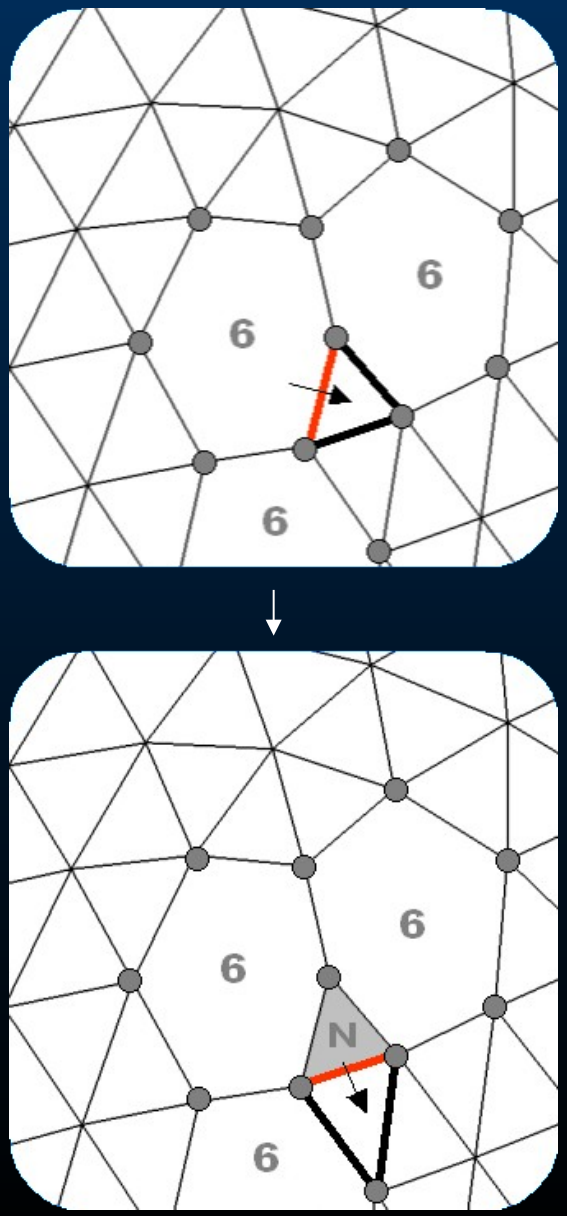
→ [3-4] on boundaries

Vertex Selection

Null patch if:

- **Valence > 6**
- **Already visited**
- **Metric-related decision**





Decimation Strategy

- Gate-based deterministic conquest
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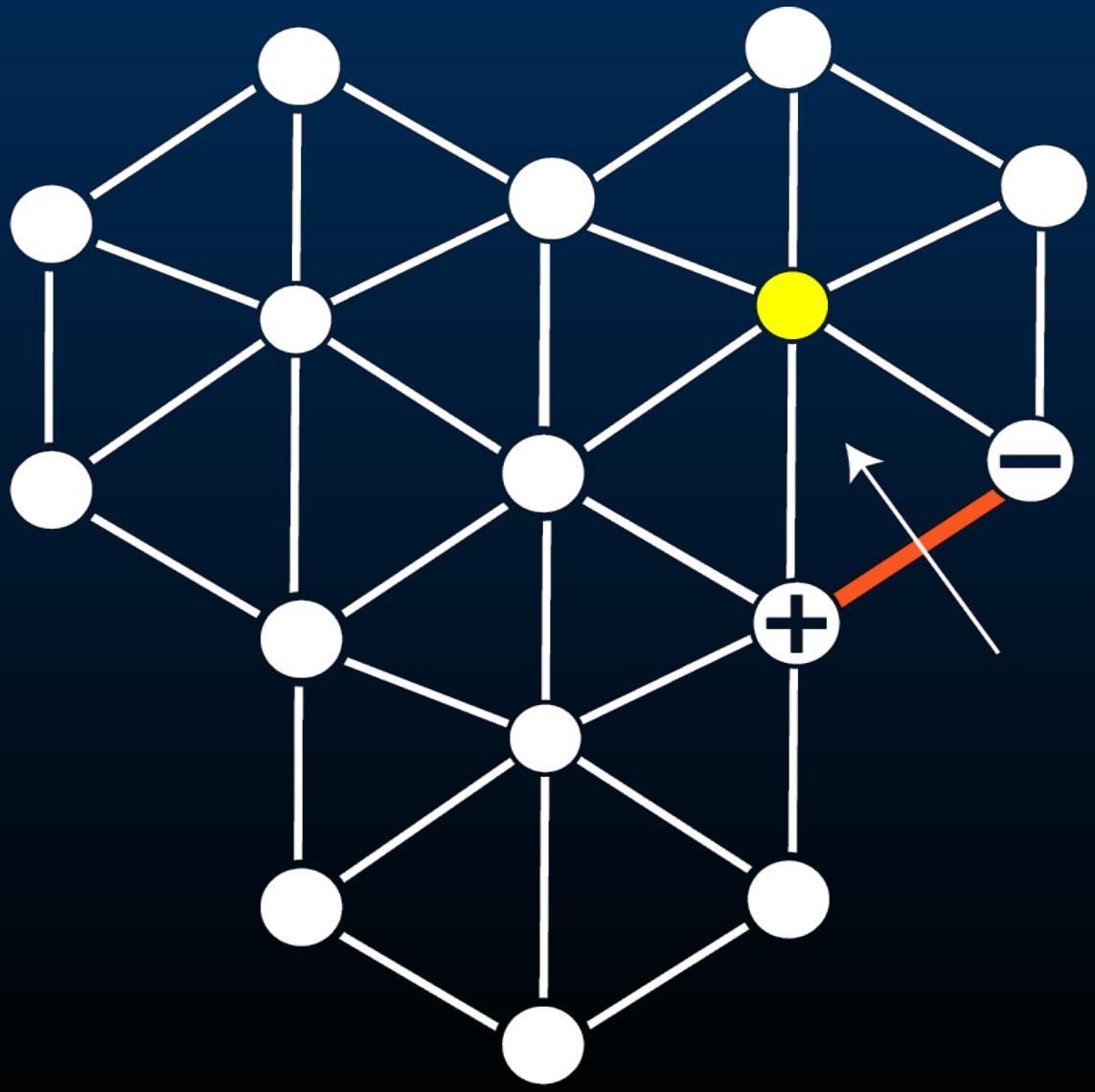
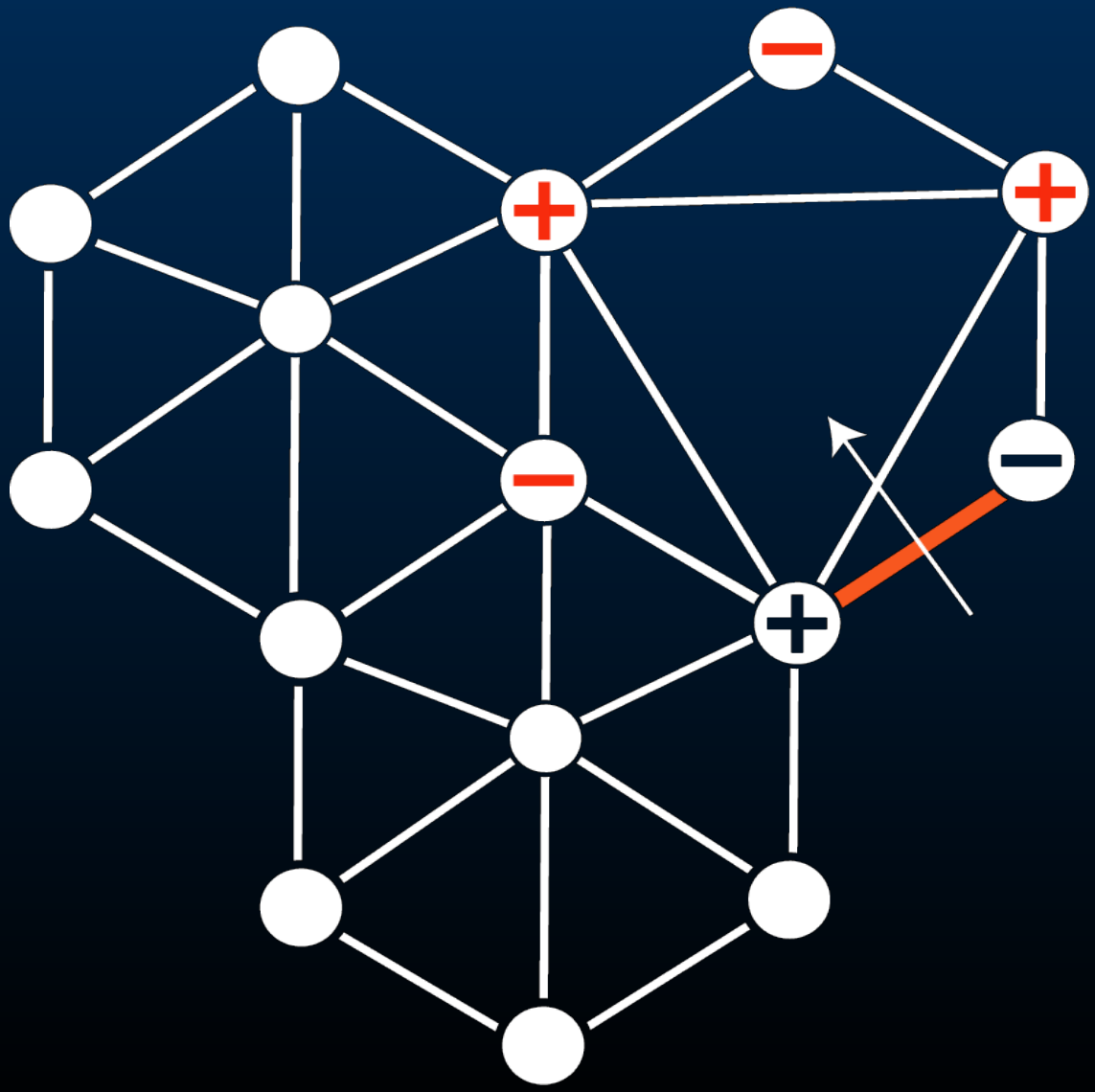
  - Cosmetic decisions
- Automatic re-triangulation
  - Favor regular remeshing
  - Look-up table

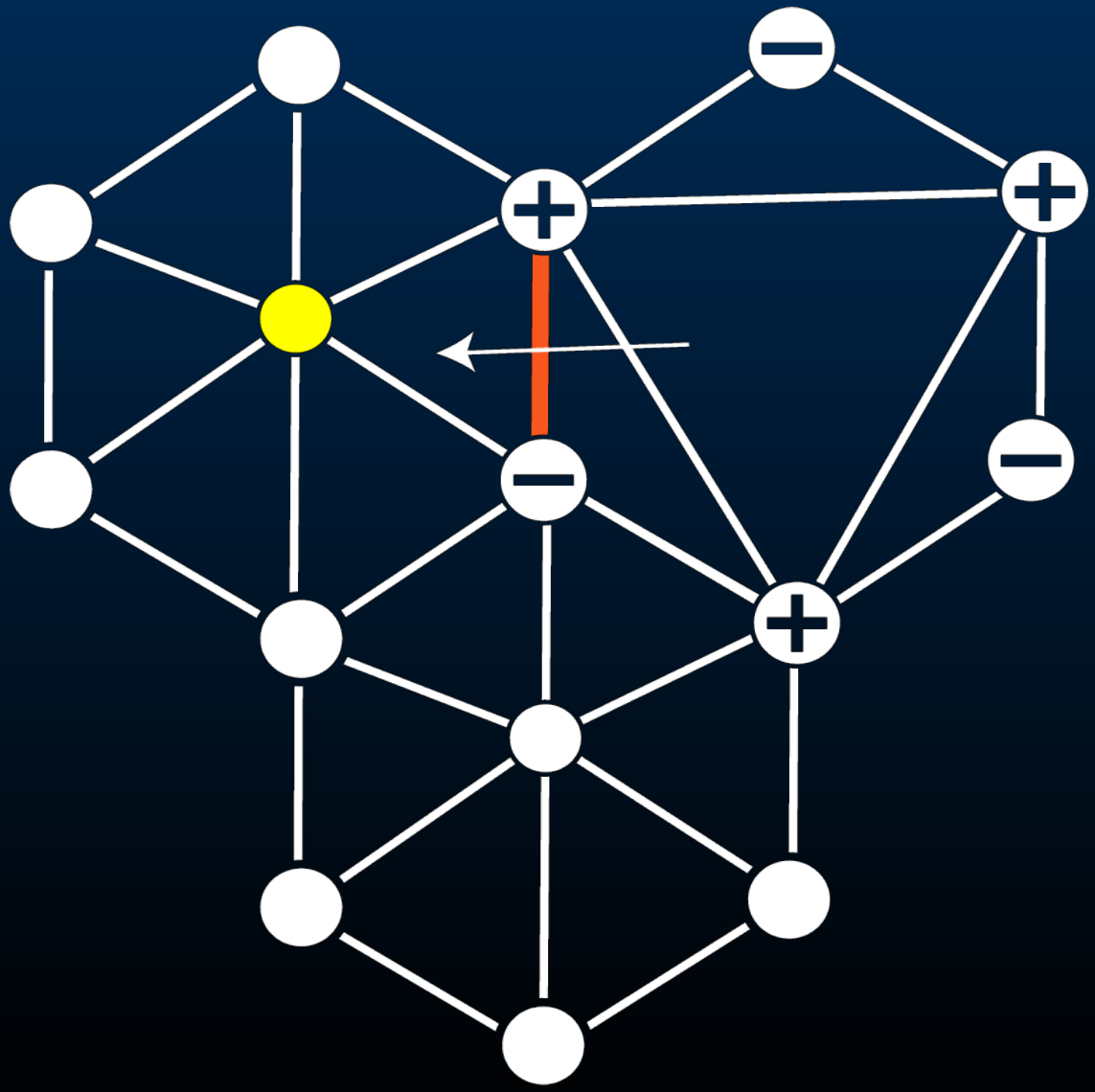
Remeshing strategy



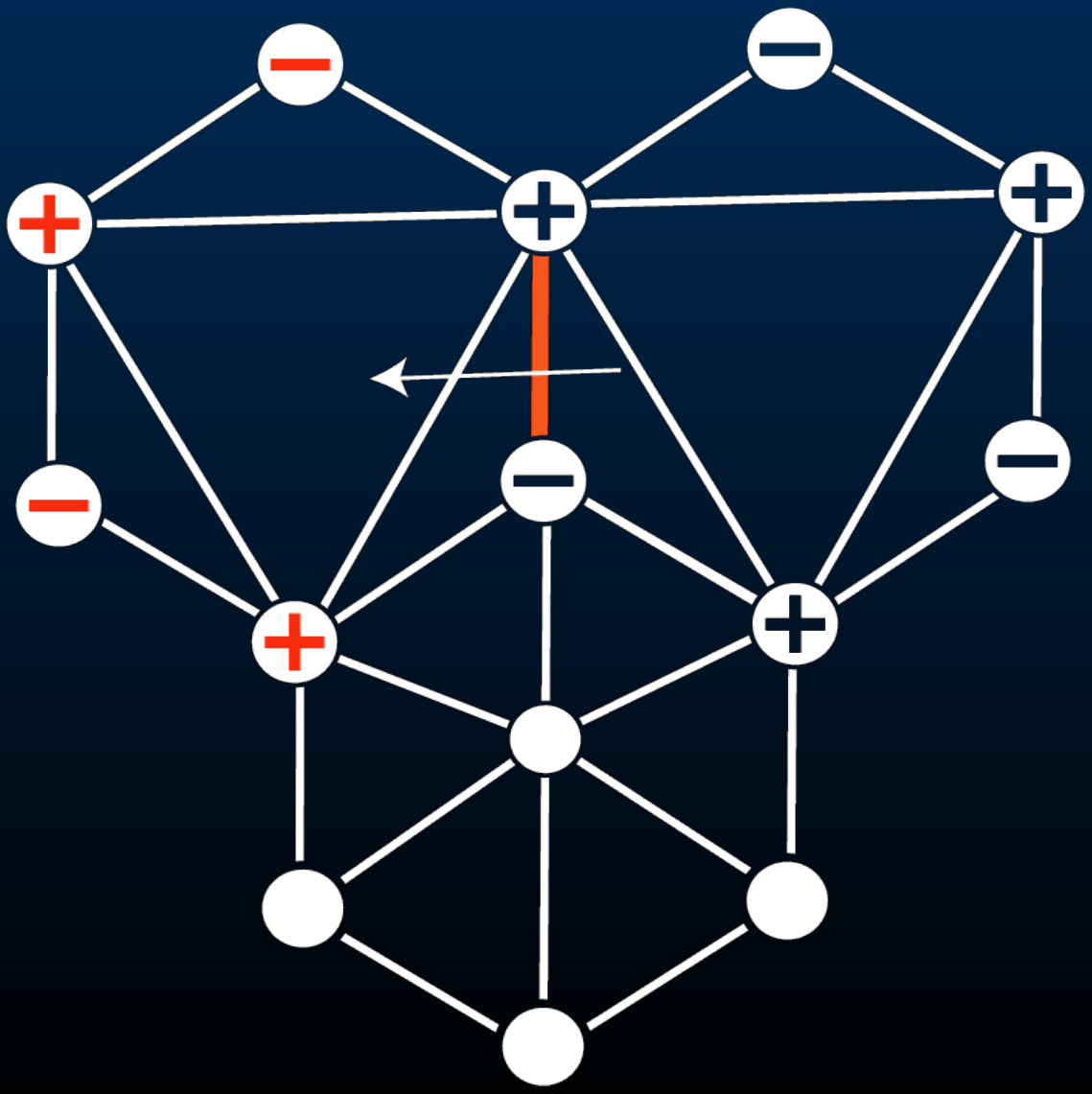
Remeshing strategy



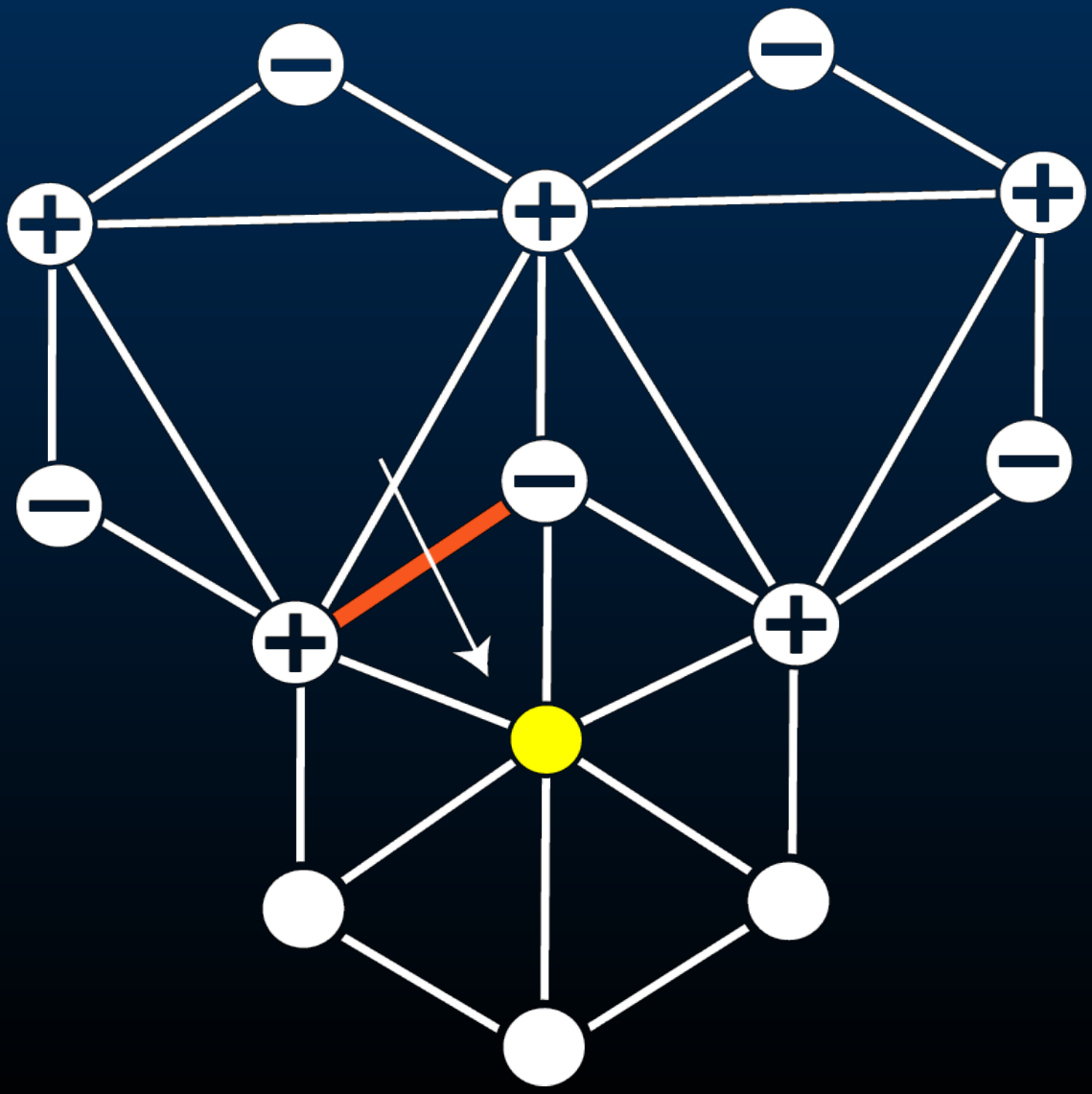
Remeshing strategy



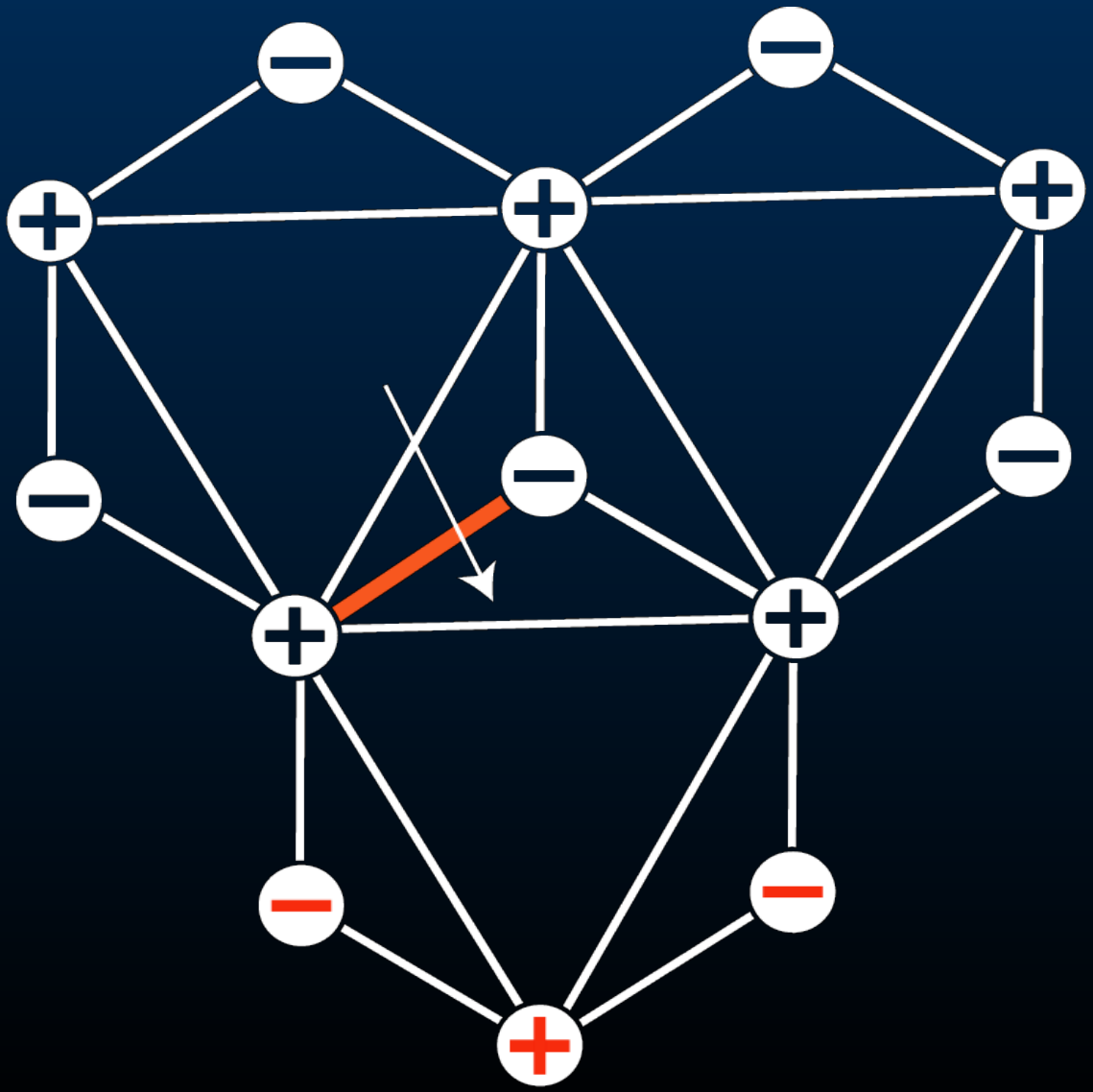
Remeshing strategy



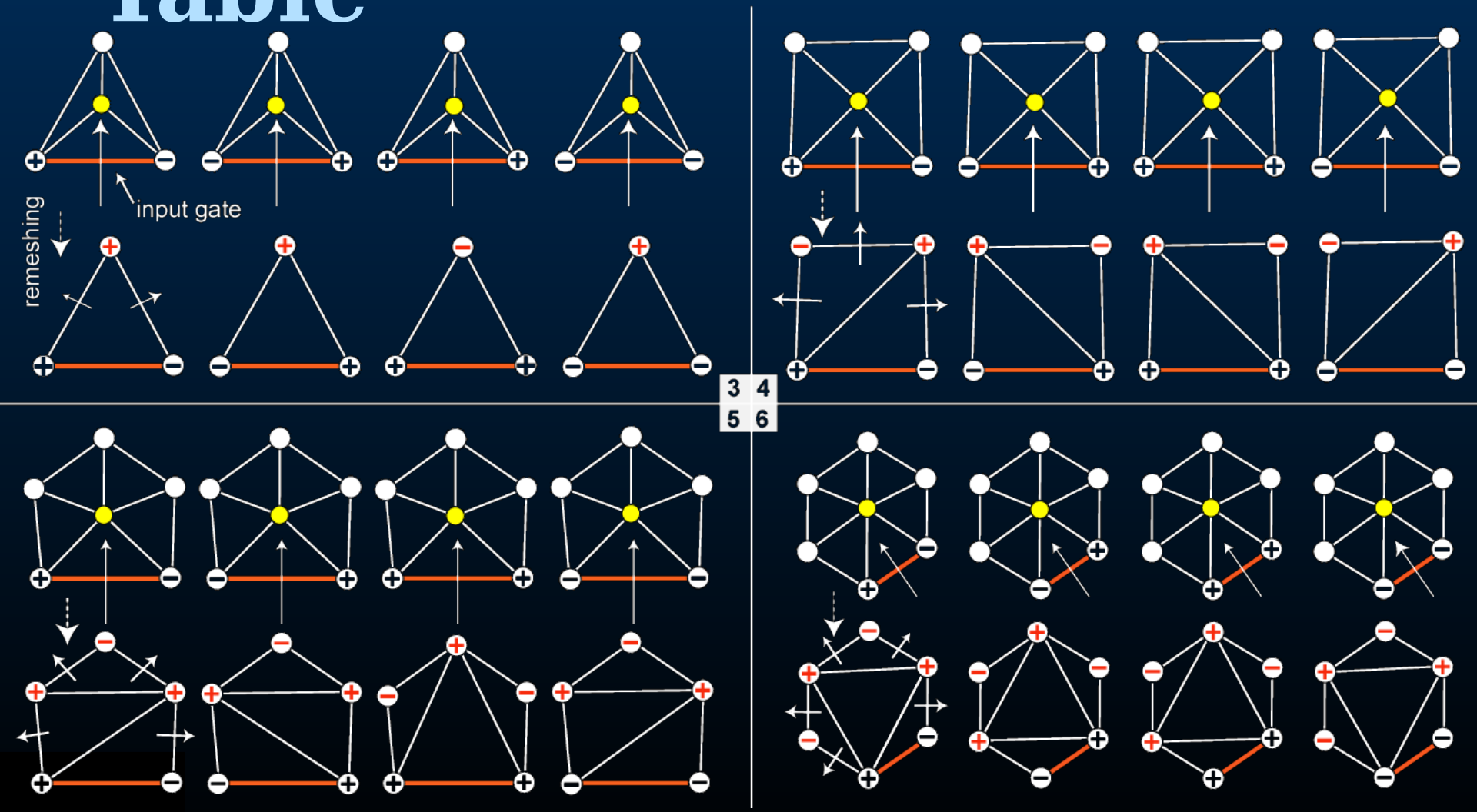
Remeshing strategy



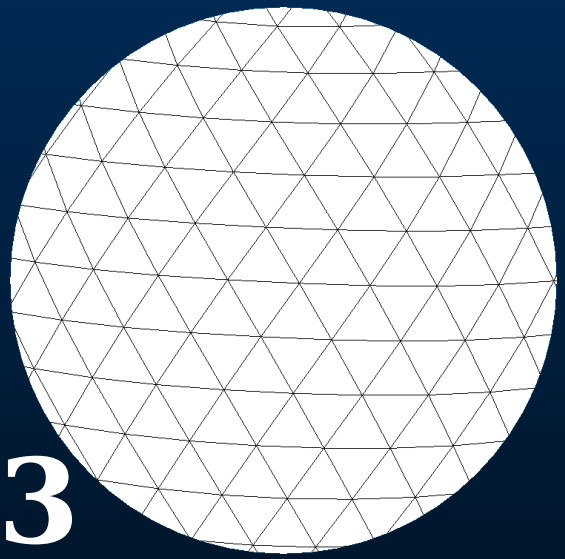
Remeshing strategy

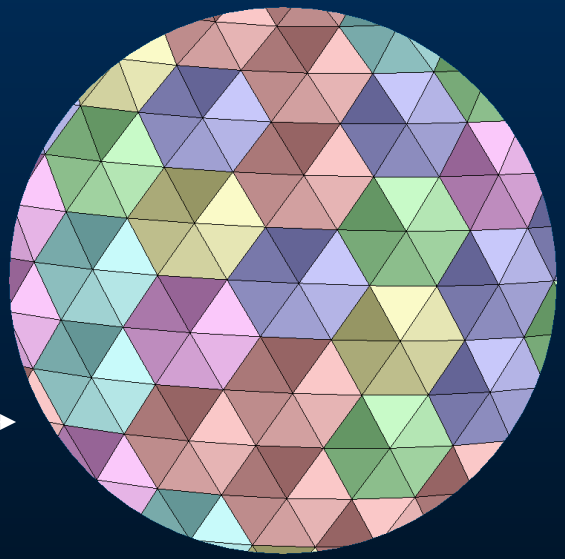


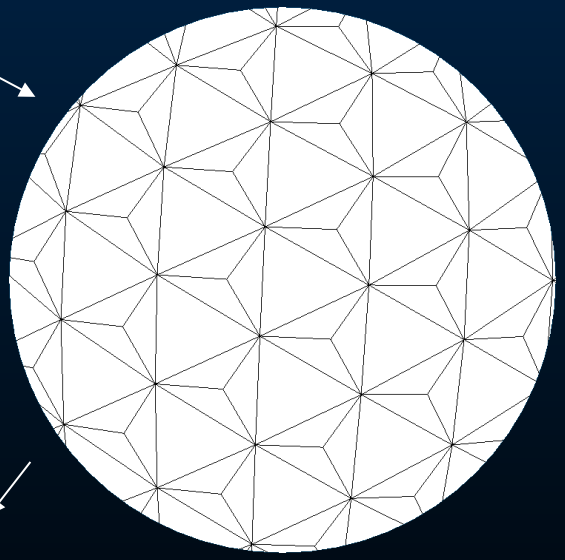
Retriangulation Look-up Table

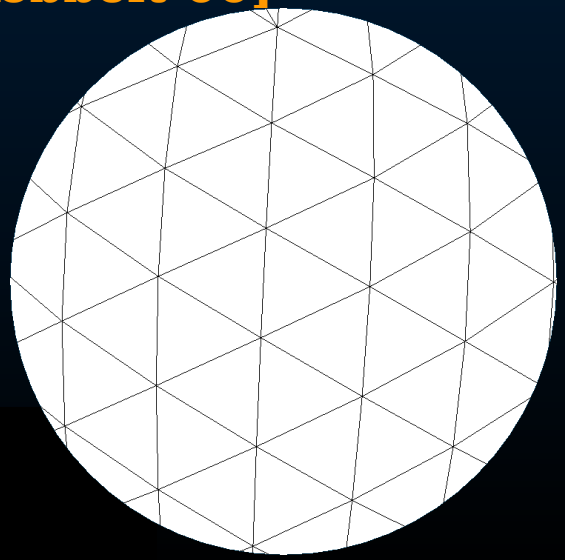


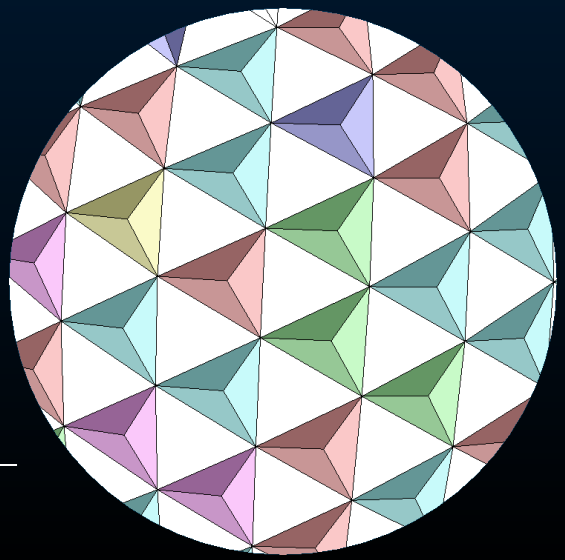
Regular Decimation











√3

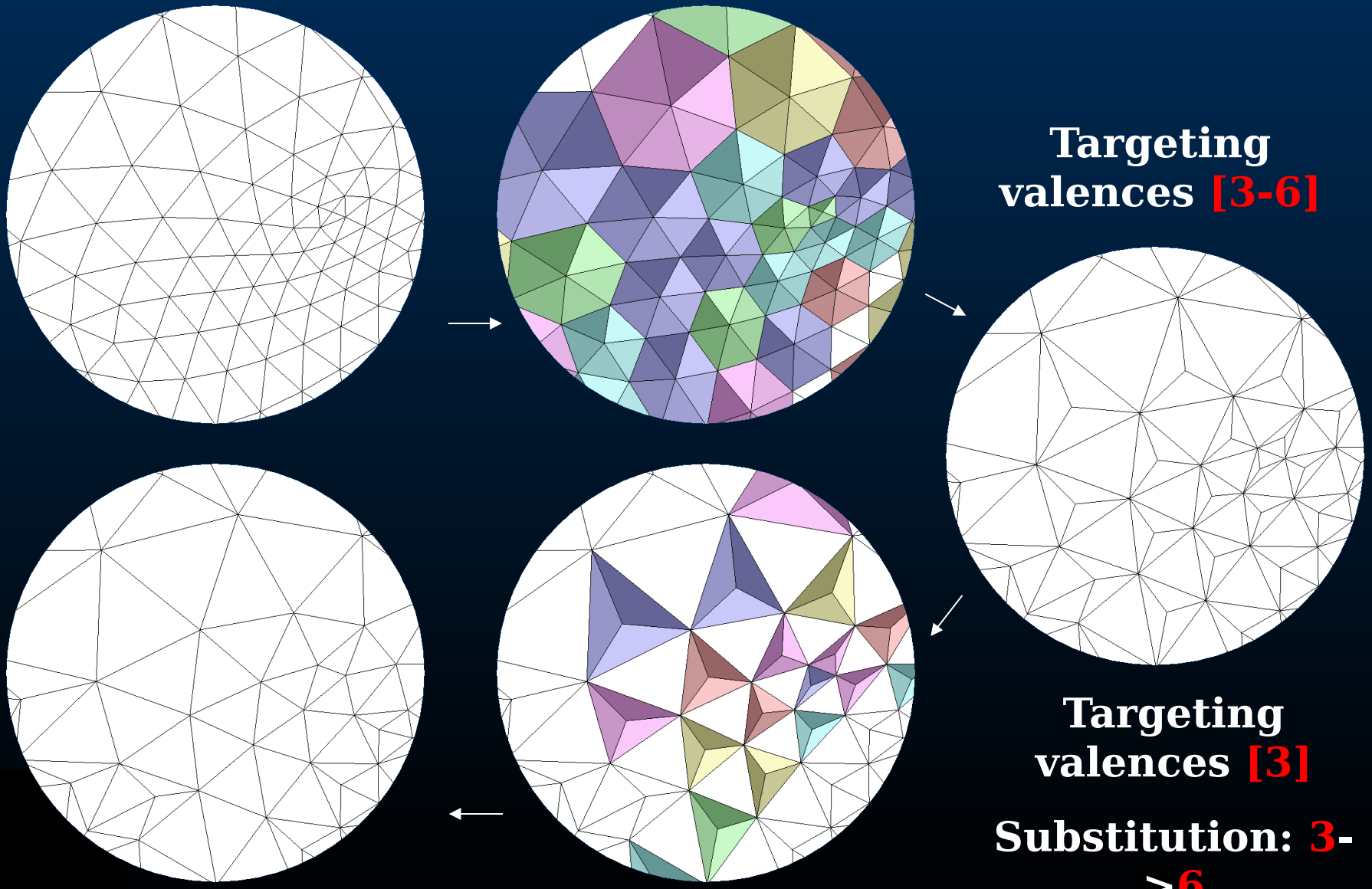
[Kobbelt 00]

Targeting valences [3-6]

Targeting valences [3]

Substitution: 3->6

Irregular Decimation

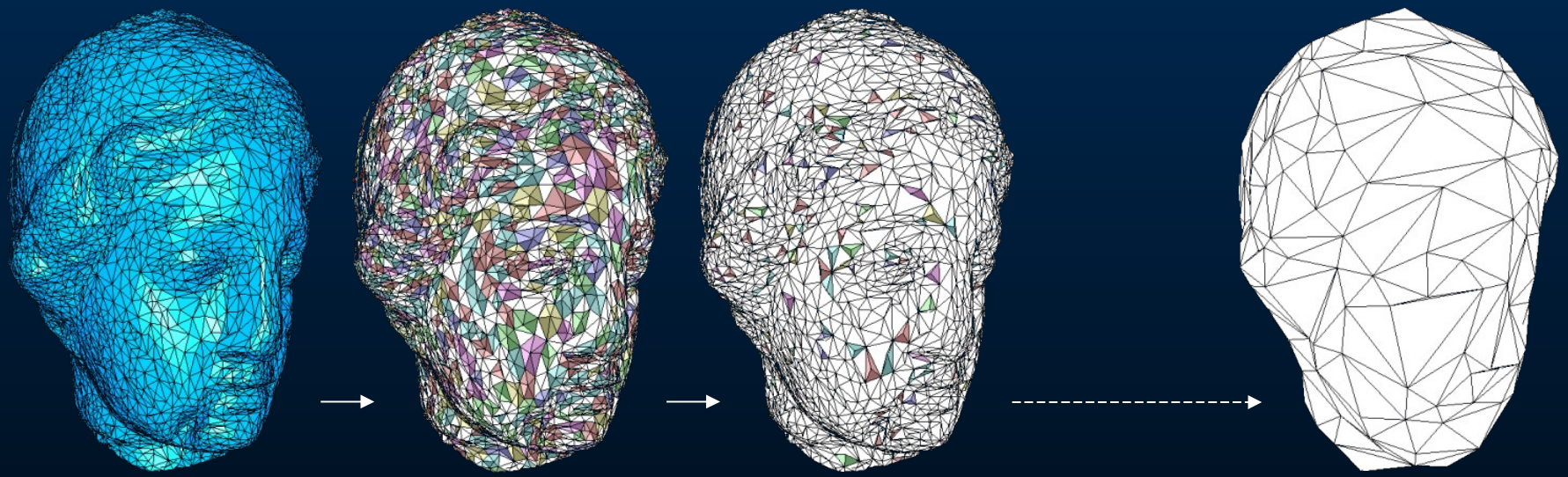


Targeting valences [3-6]

Targeting valences [3]

Substitution: 3->6

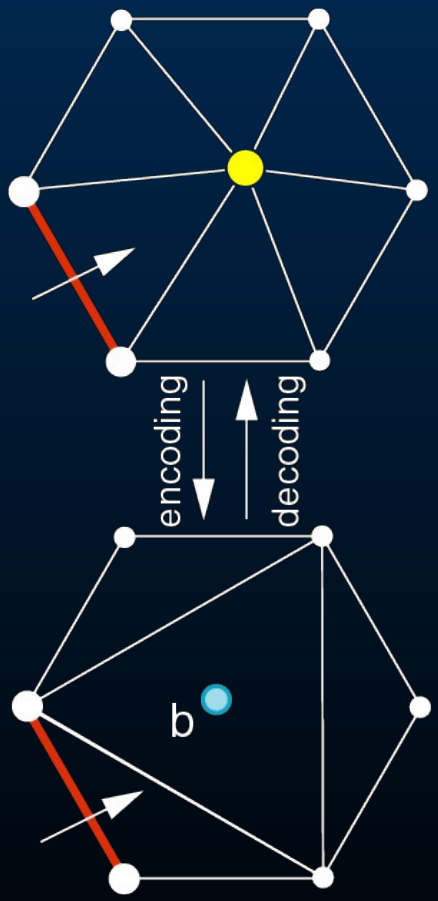
Entropy Encoding

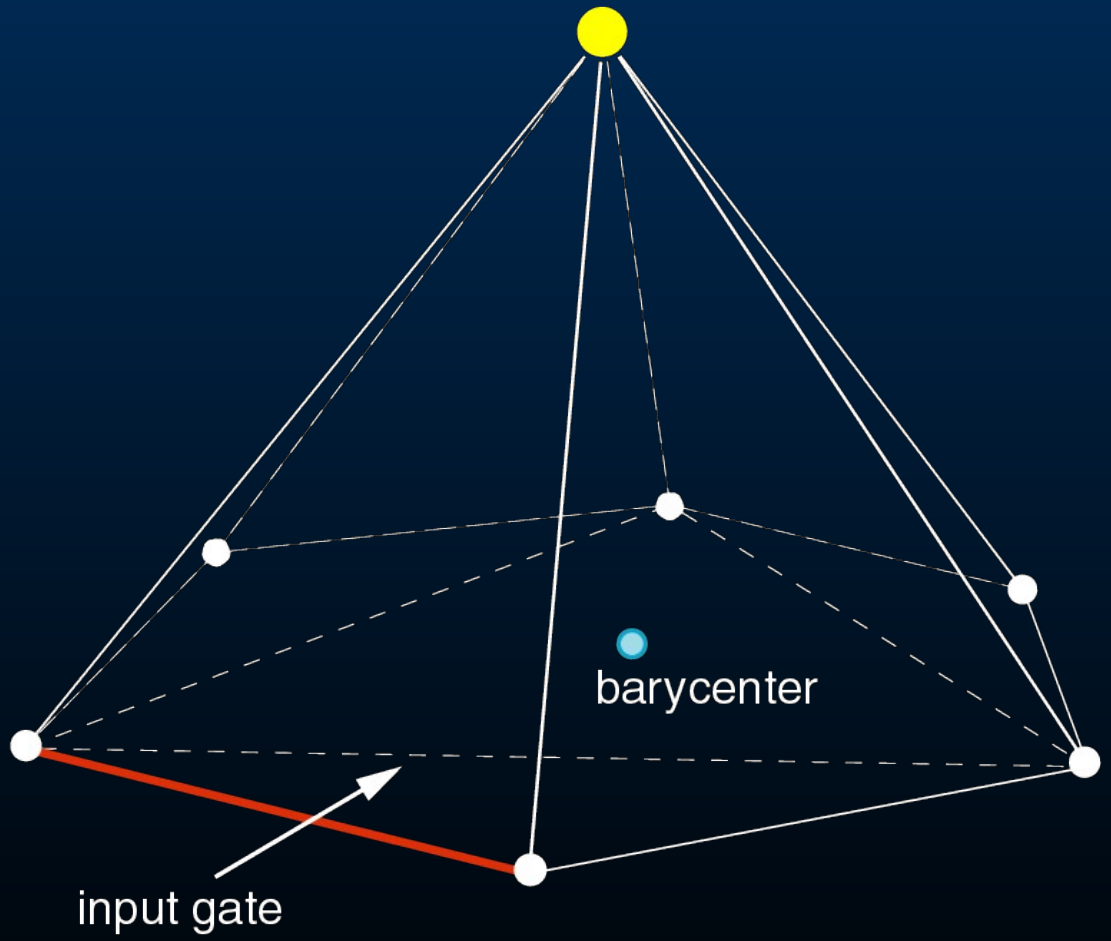


[3-6;N] [6;N] [3-6;N] [6;N]

Adaptive arithmetic encoding [Schindler

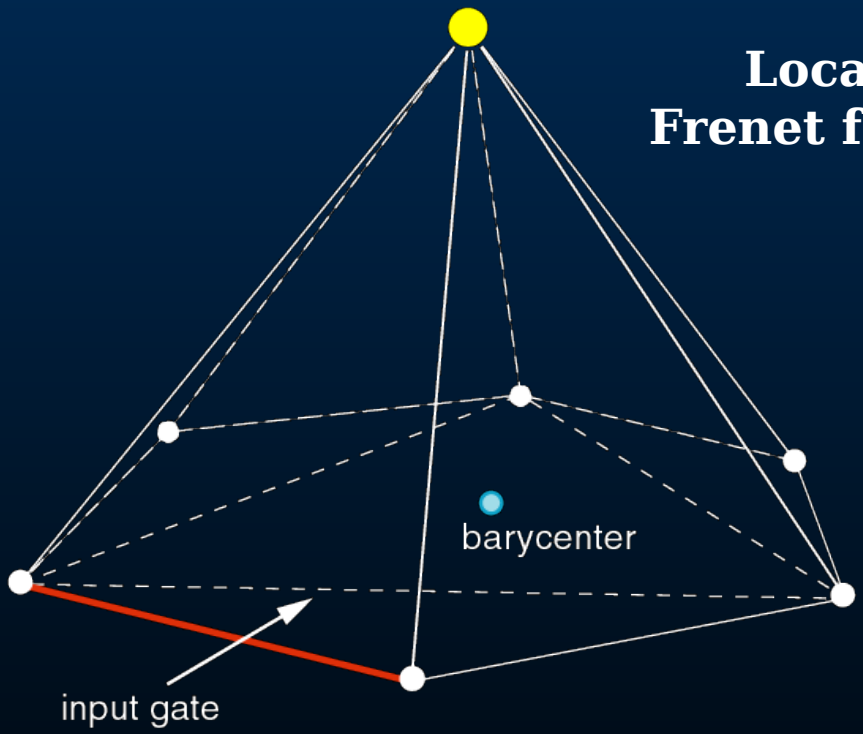
Geometry encoding



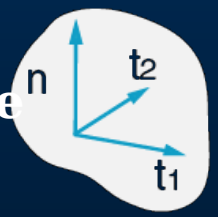


Barycentric prediction

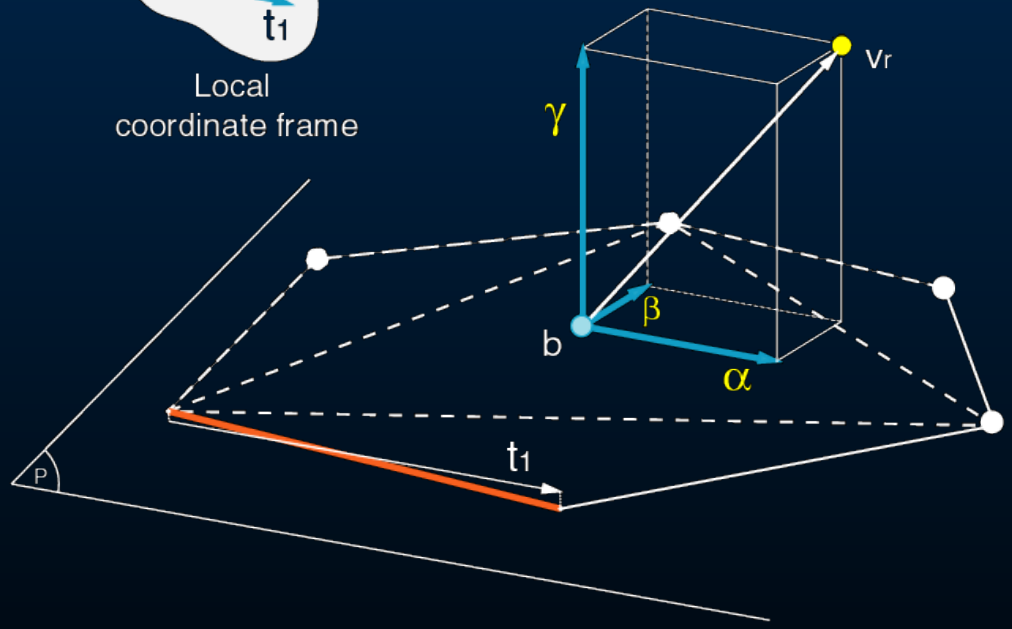
Normal / tangential separation



Local Frenet frame

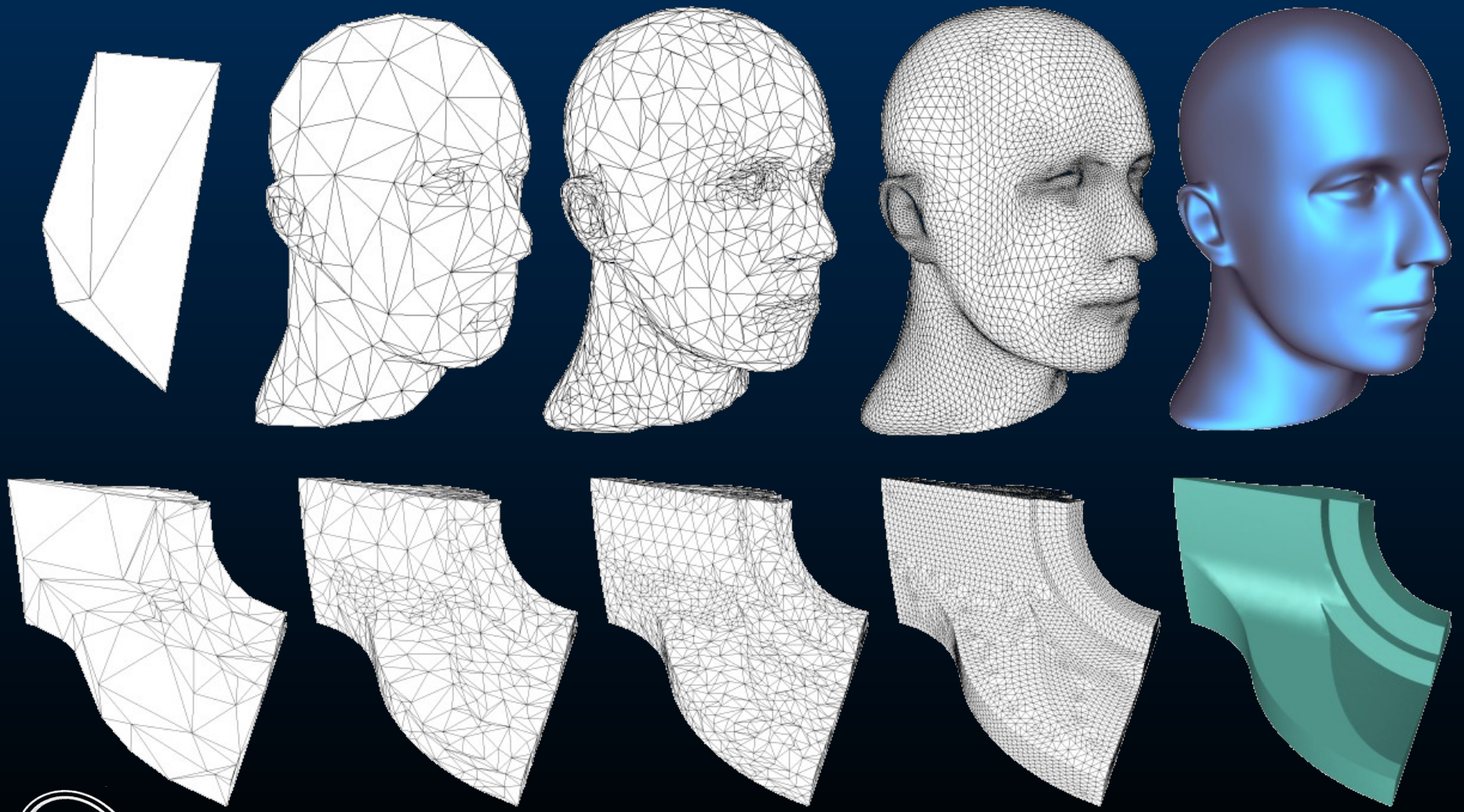


Local coordinate frame

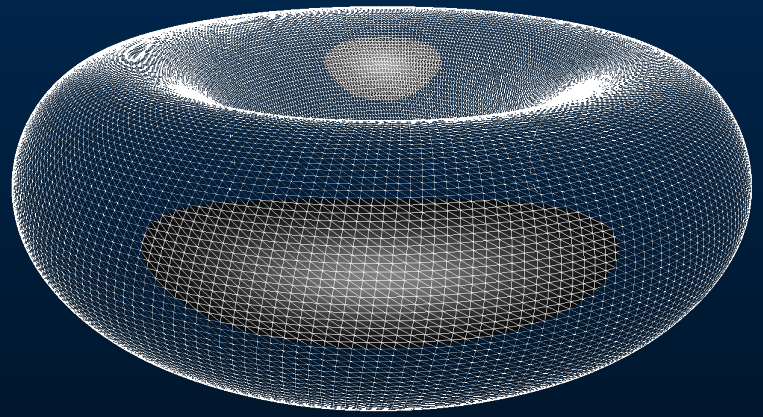


~ **[Khodakovsky et al. 00]**

Results

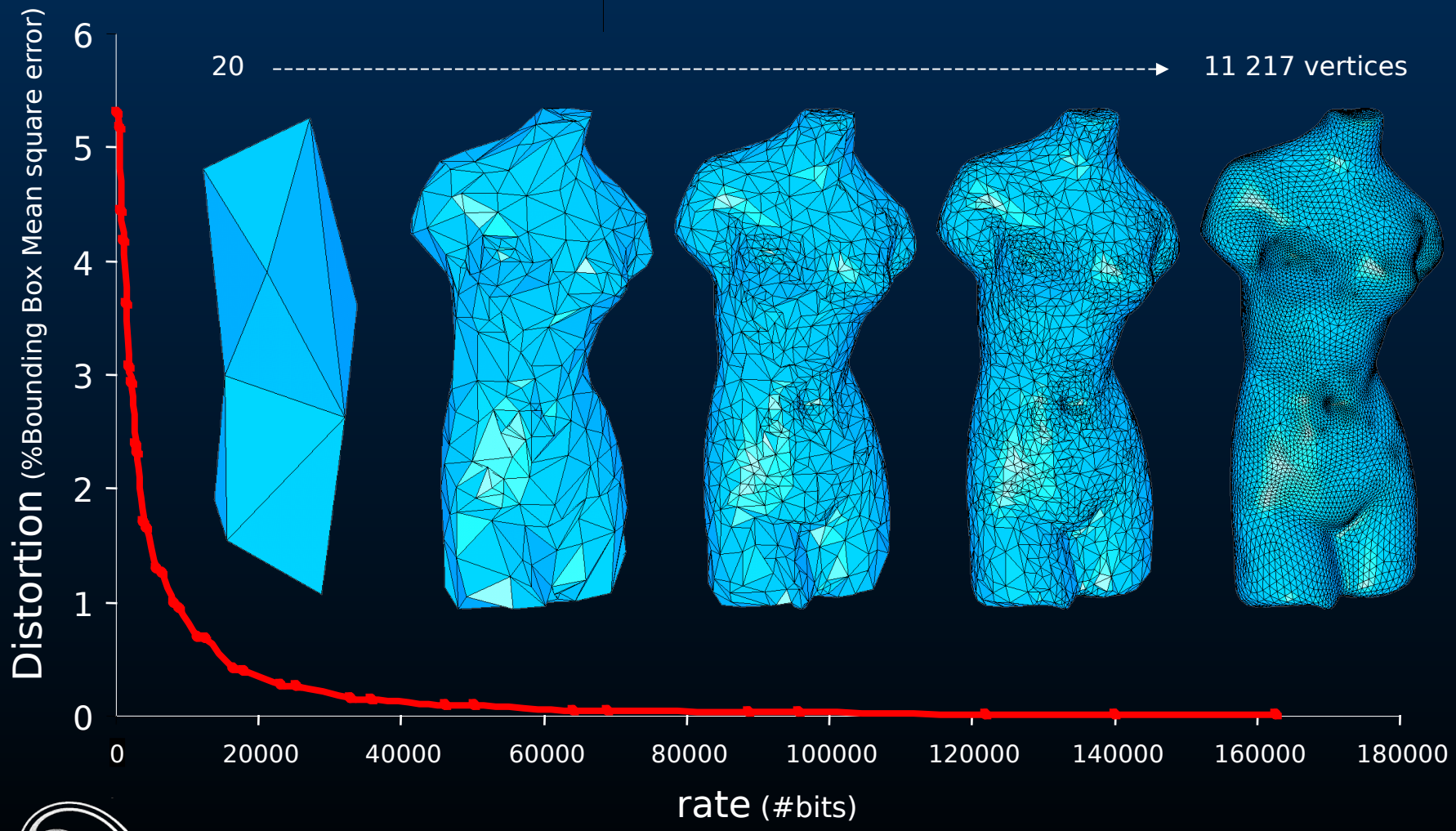


Results



Decimation	**19851 -> 4 vertices**	**Decimation**	**36450 -> 24 vertices**
Quantization	**12 bits**	**Quantization**	**10 bits**
Connectivity	**4.61 b/v**	**Connectivity**	**0.39 b/v**
Geometry	**16.24 b/v**	**Geometry**	**3.58 b/v**
	20.87 b/v		**3.97 b/v**

Rate / Distortion



Recap

Lossless methods	Connectivity (b/v)	Geometry (b/v)
Hoppe 96 (PM)	16	15-25
Taubin et al. 98 (PFS)	10	20
Pajarola - Rossignac 99 (CPM)	7.2	~17
Cohen-Or et al. 99	6	~17
Alliez - Desbrun 01	3.7	12.2

Conclusions

- No change of genus

- Requires 2-manifold meshes

+ Handle full range of triangle meshes
  irregular to regular

+ Valence & connectivity encoding
  per-vertex progressivity
  natural adaptation to regularity

zip → 4 Mb

ours → 400 Kb

+ Set of VRML meshes = 18 Mb

Future work

Geometry and attributes encoding: colors, materials, texture coord.

Entropy-driven remeshing engine?

Progressive encoding

- **Polygon meshes**
- **Topology**
- **Polygon soups**
- **Resiliency**